Systems Engineering – A Summary

This summary is based on:
"Einstieg ins Systems Engineering - Optimale, nachhaltige Lösungen entwickeln und umsetzen", 3rd Ausgabe, Zürich: Verlag Industrielle Organisation, 2004, ISBN 978-3-85743-721-2

Purpose

Project workers, as well as project managers, who want to apply the Systems Engineering methodology to their projects, get an easily understandable guide with this book. The most important principles and elements of Systems Engineering are explained briefly including their interrelations. Furthermore, a checklist is provided which simplifies determining the primary work steps.

To all colleagues who supported and encouraged us in preparing this book, we would like to express our heartfelt thanks.

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1 Introduction

Integral planning methodologies are necessary to allow companies to design successful products[1] and services. In the past, various contributions on the topic of problem-solving methodologies were published worldwide. One of these was the "Zurich" Systems Engineering.

The Origins of Systems Engineering

The origins of Systems Engineering go back over 50 years. At that time, in the context of large projects, methods were sought, which would improve project execution, as well as the planned outcome. In the 60´s, as a result, the first comprehensive publications on Systems Engineering (e.g. /Hall 1962/) appeared. At the end of the 60´s and the beginning of the 70´s, these ideas were also adopted by members of ETH Zurich (Swiss Federal Institute of Technology) staff (e.g. from /Büchel 1969/). This team from the Institute of Industrial Engineering and Management (BWI) then developed and published a cohesive and consistent planning methodology called „Systems Engineering" /Haberfellner et al. 1976/.

In the meantime, this "Zurich" Systems Engineering has been reworked (/Haberfellner et al. 1999/, /Züst 2004/) and adapted according to new knowledge and requirements. This adaptation mainly consisted of a stronger consideration of socio-technical systems and of the increasingly important analysis and evaluation of dynamic, strongly interlinked objects.

The "Zurich" Systems Engineering offers a framework and principles that lead to objective and goal-oriented designing of complex systems in cases of high complexity and/or extensive scope of a project. Systems Engineering postulates a range of principles and ways of thinking.

The "Zurich" Systems Engineering (SE) has been successfully applied many times in various planning and developmental approaches. Its success is due mainly to the framework that SE offers an interdisciplinary team of workers. This is also the reason why SE is included in the curriculum of various universities and institutions of higher education within Switzerland and around the world.

[1] The expression „product" will be used in this contribution in a much broader sense, that would mean as a physical system as well as process system. The ecological, economical and social impacts over the whole life time have to be integrated in the process of systems development (see also the wider understanding of technique in /Ropohl 1996/).

1.2 An Overview of Systems Engineering

In order to approach problems circumspectly, a comprehensive method of handling / dealing with them, in all planning phases, must be guaranteed.

On one hand – the SE-methodology - is based on the "systems approach" and "basic beliefs and principles". The main purpose of the systems approach is to enhance the understanding of systems behaviour as such; while the basic beliefs and principles set priorities for the problem-solving process (see **Fig. 1**).

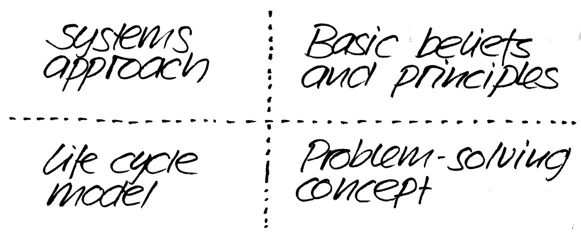


Fig. 1: The Systems Engineering Framework (in according to /Züst 1997/)

On the other hand – the SE-methodology - encompasses the "Life Cycle Model" and the "Problem-Solving Concept". The life cycle model describes the life phases of any artificial system. The problem-solving concept shows a sequence of indispensable work steps which have to be carried out to solve a distinct problem.

The SE-concept has to be interpreted for each individual case and applied in a task-specific manner. Therefore, the following must be taken into consideration when using Systems Engineering.

Systems Engineering:

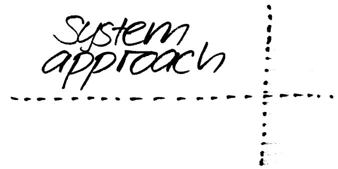
- is no substitute for talent and experience, professional knowledge and intensive personal involvement with the problem.
- in no way inhibits intuition and creativity. Systems Engineering integrates these abilities in order to achieve a goal.
- is not a ready-made recipe, but a general problem-solving methodology which should be applied task-specifically

Since the selection and application of proper methods is decisive for successful systems design and systems control, the following will delve deeper into the methodical aspects of problem-solving.

This book was conceived as a personal manual. For that reason, there is extra space at the end of each chapter for personal notes.

Personal notes:

2 Systems Approach



The Systems approach supports the process of systems design and the integration of the diverse engaged knowledge-areas and disciplines, especially the goal-oriented communication within the planning team.

Systems Approach and Systems Models

"Awareness of the variety and interdependency of relevant factors has led to a methodological development in all disciplines and fields of work, i.e. a systems approach. A first superficial consideration would bring different systems approaches to mind. They all show, especially with regard to terminology, their derivation from the field of knowledge on which their development is based. Thorough contemplation reveals the uniformity of the basic approach quite clearly. Especially in recent years, in an abstract way, this consistency has resulted in a strongly developed systems theory.

Of special importance is the holistic conception, that any problematic entity can be considered to be a system, consisting of elements with distinct relationships. The question of whether or not an enterprise, a company, an industry or a biotope is a system is irrelevant. Much more important is the fact that they all may be dealt with as very complex entities, which, with all their diverse functions, can be represented more understandably and transparently, when they are modelled as systems. This requires an applicable, flexible model structure. Models should be as accurate as possible / as concrete as necessary, but models inevitably abstract from reality and reflect the planners view and comprehension of reality."

(quoted from W. Daenzer's preface, in /Haberfellner et al. 1976/)

2.1 Socio-technical Systems

In a corporate context, not only technical, but also socio-technical systems must be designed, analysed and evaluated. Human beings with all their interactions are part of the system. Here we will speak about involved and affected participants (see **Fig. 2**).

Socio-technical systems are open, interlinked and dynamic and therefore complex:

Openness: The current system contains active relations to the external environment. The system is not isolated.

Dynamism: The elements and relationships in the system change over time.

Complexity: Complexity is a function of the diversity and number of elements and relationships in a system. The behaviour of complex systems is not deterministic and therefore principally unpredictable. Under specific conditions they may run out of control i.e. behave chaotically. On the other hand we know self-organising systems that build up stable structures and behaviour despite their complexity.

Complex systems are also characterised by the (often temporally delayed) appearance of positive and negative feedback loops, in as far as they can be modelled as intertwined cause-effect-chains.

The behaviour of socio-technical systems is often counterintuitive (e.g. **Fig. 2**).

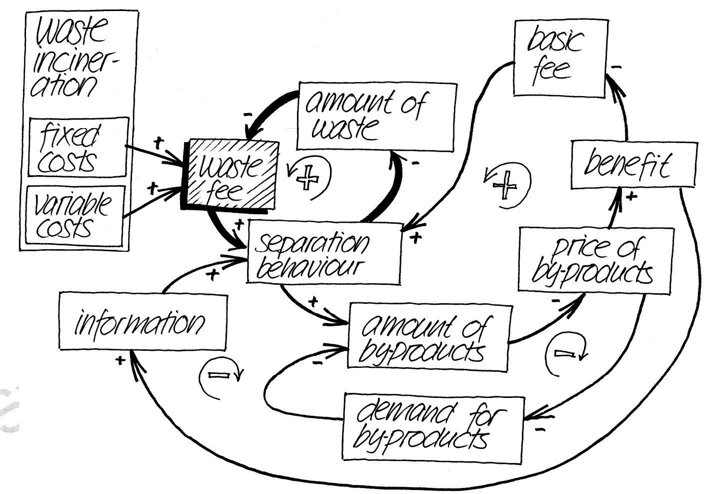
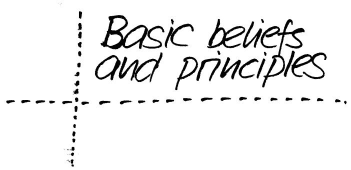


Fig. 2: Model of a dynamic system, showing the impact of elements on others (Example „waste fee“ from /Züst 1997/

Personal notes:

3 Basic Beliefs and Principles



Basic beliefs and principles suggest how the planning and development team should generally act in the problem-solving process.

3.1 Considering Time-related Changes

Systems change over the course when developing a system model. That is why the planning team must constantly deal with new situations. There are two different aspects to consider:

- anticipation of future changes in the environment and their integration into the planning process based, for example, on trend analysis, and
- evaluation of previously planned steps and interim decisions against new relevant knowledge, and adaptation, if necessary.

3.2 Thinking in Alternatives / Thinking in Options

The goal of Systems Engineering is to comprehensively consider all relevant aspects of the problem in the planning process. Thinking in alternatives and options as well as using scenarios to examine these alternatives plays a central role in the synthesis, as well as analysis of solutions to the problem.

3.3 From an Overall to a Detailed View

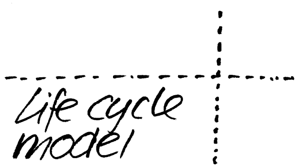
A further element of successful planning is the effective structuring of the working levels. There are two ways in which this should be done:

- on the one hand, systems should be structured hierarchically and specified with an increasing degree of detail.
- on the other hand, this influences the planning methods. The heuristic principle "From an Overall to a Detailed View" illustrates that it is advisable to first make a comprehensive situation analysis, set general goals for the total system and design a rough draft solution on a relatively general level. In the course of the problem-solving process the goals and concepts should be developed – step by step – in a more and more concrete and detailed manner.

In practical application, the principles „from an overall to a detailed view" or „from the abstract to the concrete" and of „thinking in alternatives " should be used in combination. This means that in the problem-solving process, as one moves from overall view of the system to a detailed view of the solvable problem, one must be aware of the alternatives at each planning level and select the alternative that is considered the best given the current knowledge of system and the problem-solving goals.

Personal notes:

4 Life Cycle Model



The life cycle of an artificial System comprises a number of distinct stages.

4.1 An overview of the Life Cycle Model

The "Life Cycle Model" roughly divides the life span of a distinct artificial system into development, realisation or production, utilisation and disposal. The related activities can be subdivided into partial phases. The development phase can be broken down into incentives for systems design, preliminary study, main study and detailed study. Through this, the system will successively be developed according to the general principle „from the abstract to the concrete" (**Fig. 3**):

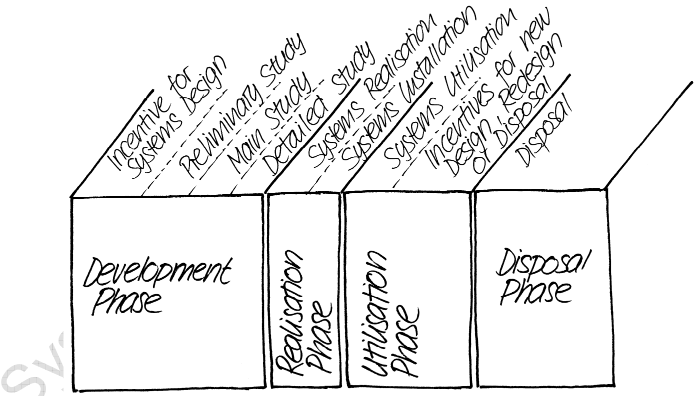


Fig. 3: Life Cycle Phases

In the following, the life cycle model phases will be described individually.

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4.2 Initiative for Systems Design

The first phase in the development stage is „systems design initialisation". This rather unstructured phase encompasses the time period between becoming aware of a problem and deciding to solve it. In practice, this is also called the project preparation phase.

Purpose:	Inform and sensitise decision-makers about a possible problem, develop problem awareness and clarify willingness to act
Result:	The decision of the decision-makers to either deal with the problem within the scope of a study, or to defer it.

The initialisation has a decisive influence on the subsequent planning process. The more or less concrete task formulation at the beginning of a study is critical for its analysis and must be enhanced in accordance with the client's interests.

4.3 Preliminary Study

Formulation of and agreement on the problem and its boundaries is the central issue, as well as the definition of requirements for the system to be changed or newly designed. The problem must be regarded comprehensively. The relevant relation with the system's environment and all influences on the system itself are significant.

The problem-solving process, within the framework of a preliminary study, is characterised by the fact that important decisions must be taken though there is not very much information available (yet). Correspondingly, the preliminary study has a significant effect on the results of the following planning-stages.

The decision-makers have to close the preliminary study by making an important decision: Plans which are not promising should be discarded as early as possible. For the purpose of concentrating efforts, less promising undertakings should be replaced by better ones.

Purpose:	The preliminary study is a clarification process, especially regarding problem formulation and goal setting. Possible solution concepts must be worked out sufficiently, and checked for feasibility, so that the decision-makers can evaluate and make a decision.
Result:	The result of a preliminary study is a solution concept, i.e. a conceptual framework that must be worked out in more detail in a main study or a suggestion to terminate the problem-solving process.

A further goal of a preliminary study is to determine if there really is a need for a new or modified solution to address / or to solve the problem identified in the previous phases.

Methods, which support qualitative and/or semi-quantitative analyses and evaluations, are of special interest insofar as the necessary planning information is usually incomplete and inexact.

The quality of a preliminary study can be tested with the following questions /Züst 1997/:

- Has the problem been defined clearly enough?
- Who is affected by the project and who is involved?
- Are the relations to the environment clear?
- Are the options for systems design known and defined clearly enough?
- Is the client in agreement with the information listed above?
- Are the requirements for problem-solving (goals and general framework) clear?
- Is there adequate overview of basic, conceivable solution concepts?
- Can the suitability / effectiveness of these alternatives be evaluated?
- Is it possible to make a decision for a certain alternative based on this evaluation?
- Can the decision be justified logically and understandably?
- Are all critical factors known?

4.4 Main Study

Based on the (abstract) solution concept chosen, the main study works out the design of the entire system. Overall concepts should be generated, which allow a well-founded evaluation of the effectiveness, feasibility and economic efficiency of the designed system.

In the main study, the area of study is consciously narrowed down and concentrated on a set of possible solutions. The environment is only relevant as far as its effects on the further design of concept drafts.

Purpose:	Within the framework of the main study, intensified gathering of information is essential. Alternative concepts must be developed and evaluated with regard to their feasibility, effectiveness, and profitability.

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Result:	The result of the main study is the overall concept. The overall concept provides the framework for further development and realisation

The quality of a main study can be tested with the following questions /Züst 1997/:

- Is the recommended overall concept convincing and realisable, regarding functional, economical, personnel and organisational aspects? Are the necessary means and organisational prerequisites known?
- Is there an overview of conceivable alternatives?
- Are the critical components known?
- Are the people working on the search for a solution sufficiently involved or informed?
- Is the situation ready for a decision? Can the decision be accepted and justified internally and externally?
- Are the priorities for further specification, respectively realisation, clear?

The concept alternatives, compared to the preliminary study, are more comprehensive and especially more detailed. In this stage, e.g. efficiency and investment calculations play a central role.

4.5 Detailed Studies

Within the framework of detailed studies, detailed solution concepts for partial problems, i.e. functions and components of a system, are worked out. The bases for detailed studies are information and results created within the main study. The area of study is narrowed down as much as possible. Distinct subsystems are tackled under specific aspects.

Purpose:	Working out of detailed concepts on the basis of specific, sound, evaluated information and partial concept alternatives. Also, all relevant information to realise the solution is provided.
Result:	Detailed concepts and, if need be, realisation concepts, as well as ideas concerning the disposition of existing systems and its elements.

Note that individual detailed studies can extend over several system levels. The decomposition of an overall concept can be accomplished in several partial steps. Also, the partial concepts developed within the scope of detailed studies must constantly be co-ordinated with each other.

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The quality of detailed studies can be tested with the following questions /Züst 1997/:

- Do the detailed concepts meet the requirements resulting from the overall concept?
- Can detailed concepts be integrated into the overall concept and among themselves ? Do they fulfil the functions they were conceived for? Do the detailed concepts have qualities which are not desirable for the overall concept?
- Are the detailed concepts concrete enough to be realised?

4.6 Systems Realisation

Systems realisation means the implementation of a system concept, i.e. the production of a designed and planned system. This encompasses the individual systems components, which are produced within the organisation or acquired externally. It also includes the respective organisational framework.

Purpose:	Acquisition or production of the individual systems components, orderly / systematic assembly and preparation for systems introduction.
Result:	A functioning / working but not yet deployed / introduced system.

Parallel to the production of the system itself goes the creation or acquisition of further important hard and software components, i.e. training materials, systems documentation and user manuals.

4.7 Systems Installation

Systems installation means turning the system over to the user, as well as explaining how it works and how to use it. Simple systems, after appropriate preparation, can be introduced as a whole without much risk. In a concluding review the effectiveness and efficiency of the system should be evaluated.

Purpose:	Put new system into operation, and, if need be, dispose of old system.
Result:	The ready–to-use system is turned over to the system user.

After a successful installation of the system, the SE-project is generally terminated.

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4.8 Systems Utilisation

Systems utilisation means the system is being operated and handled by the user.

Purpose:	Application and use of the system and test of the performance, if necessary, while adapting the components.

Experiences gained and suggestions for change should be gathered systematically and, if possible, linked with the individual functions of the system. This provides the basis for improving the current system or for the design of analogous systems.

4.9 Initiatives for new Design, Redesign or Demanufacturing

When it becomes obvious that the system in use requires significant redesigning or even a new design, this is the incentive for a new preliminary study.

Purpose:	Make decision-makers aware, develop problem consciousness, and clarify willingness to act.
Result:	Decision by the responsible persons, either to deal with the problem in a new study, or to defer it.

For minor improvements and changes, this course of action is not necessary. Such adaptations can be implemented, while the system is working.

4.10 Disposal Phase

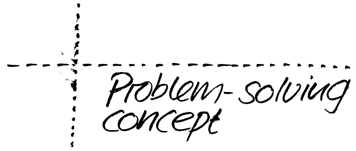
The disposal phase covers the final disposal of a system. After the disposal phase, the original system does not exist anymore. Individual components of it can be reused in the same or similar way in other systems.

Purpose:	Organised disposal of systems.
Result:	Disposed system.

The disposal phase should, if possible, be part of the planning activities. The system disposal should already be considered during the development phase.

Personal notes:

5 Problem-solving concept



The generic problem-solving concept (Problem-Solving-Cycle) is a basic structure for tackling any defined big or small problem in any life cycle phase of a system. It proposes a series of topics, which should be tackled - principally in an iterative manner - within a distinct planning step. The results of the individual planning steps should be coherent.

5.1 An Overview of the Problem-solving concept

The problem-solving concept describes the indispensable work steps in order to solve a task within the scope of any planning stage.

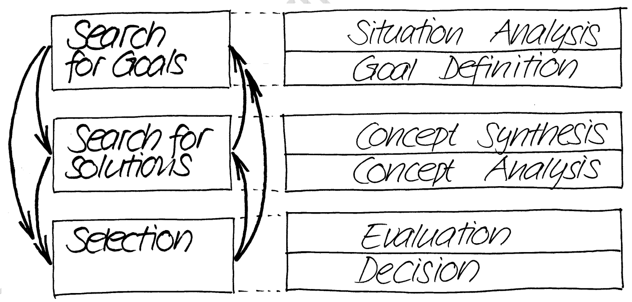


Fig. 4 Problem-Solving Concept (according to /Haberfellner et al. 1976)

The individual planning steps, as presented generally in **Fig. 4**, show subtasks, which must be accomplished. The respective effort depends on the specific problem.

Problem-solving should start with a definition of the system and a comprehensive situation analysis **(Fig. 4**, **Fig. 5**). Understanding how the system functions and its interactions with its environment is the foremost purpose. Especially in preliminary studies, and for the most part in main studies, usually in an early planning phase, the relations to the system environment, and/or external influences on the system, are important and need to be carefully considered.

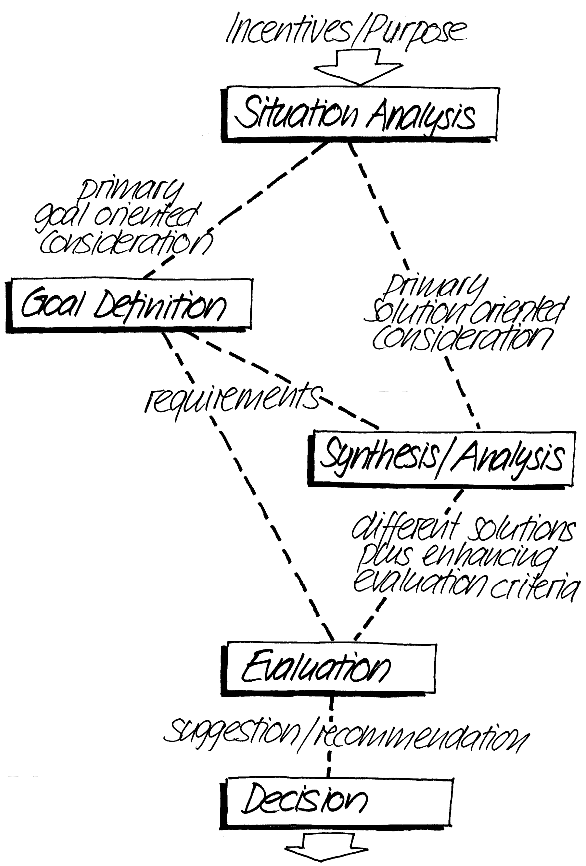


Fig. 5: Problem-solving concept and corresponding information flow (according to /Haberfellner et al. 1976/)

After the situation analysis the goals are formulated and the initial problem definition must be reconsidered / revised. Here the preferences of the decision-

makers / stakeholders are taken into consideration, and the facts are sorted through in the situation analysis.

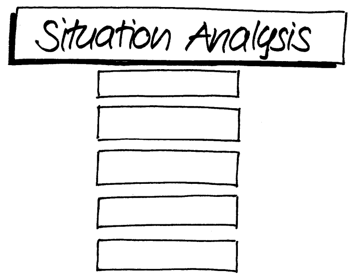
Concept synthesis and concept analysis are the next steps. Here the widest and most comprehensive solution spectrum should be developed and tested for its feasibility. Realisable solution alternatives are the result.

The finalising steps encompass the evaluation of the alternative solutions and the decision about the optimal one.

In the following, the individual steps of the problem-solving concept are presented in detail.

Personal notes:

5.2 Situation Analysis



The situation analysis is the first work step It includes the investigation of the current situation. The results of the situation analysis are the basis for goal definition and the search for a solution.

Purpose: Situation analysis accomplishes the following:

- Holistic anticipation / grasping of the problem under all relevant viewpoints
- Outlines the possible approaches and margins for new concepts and the available scope for new concepts and measures
- Acquires an information basis for the following operational steps, especially for goal definition and concept synthesis.

Contents: The situation analysis is the systematic investigation and description of a perceived problematic state or behaviour of an object (real world area).

The situation analysis

- is influenced in condition and trend determination by the past, present and future,
- is open, regarding goals, solutions and utilisable means and
- is the basis for all the following steps.

Process: The contents of the situation analysis passed through cyclically are:

- task analysis

- analysis of the actual state and behaviour of the system in mind:
  - defining the system and environment boundaries
  - analysing structure and function of the system
  - analysing the environment
  - analysing strengths and weaknesses (**Fig. 8**)
  - root-cause-analysis
- analysis of the future / future scenarios / trends:
  - prediction of behaviour of the environment
  - prediction of behaviour of the uninfluenced system
  - opportunities-threats analysis (**Fig. 9**)
- brief conclusions, final problem definition

Systems Definition as a specific Modelling Task:

In conjunction with defining boundaries for a system, the terms *system to intervene*, *external systems* and *environment* are important:

- The *system to intervene* includes the areas of reality, in which intervention and changes are possible within the scope of working on the problem.
- *"Environment"* includes systems outside of the system to intervene.
  The term environment can lead to misunderstanding, if only given an ecological meaning. Therefore, the term environment is used in its wider sense in the following.
- *External systems* describe the relevant part of the environment for systems investigation and design. They have relevant relations to the systems to intervene.

The crucial prerequisite for successful systems design is the comprehensive understanding and sensible separation / delimitation of the problem to be solved. On the one hand, systems interventions should not merely cure symptoms but lead to real improvements. On the other hand, one should avoid concepts which exceed available personnel and material potentials, or are not consistent with the time requirements for solving the problem. Systems definition, therefore, has a decisive influence on the problem-solving process. First, the area must be defined in which intervention and alterations are possible. Second, the area, which should be investigated within the framework of the study, must be defined.

The process of defining the system can essentially be simplified through the analysis of possible impacts, by which the individual influences on the project can be determined (**Fig. 6**). The extent of the influences over the course of time and their eventual feedback can be further investigated in the following.

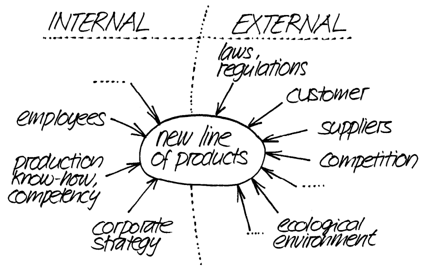


Fig. 6: Example of impact analysis for a new line of products, distinguishing internal and external impact factors

Additionally, the heuristic principles of modelling systems as black-boxes, regarding them under different aspects and structuring them hierarchically can be helpful in the process of defining system boundaries (**Fig. 7**).

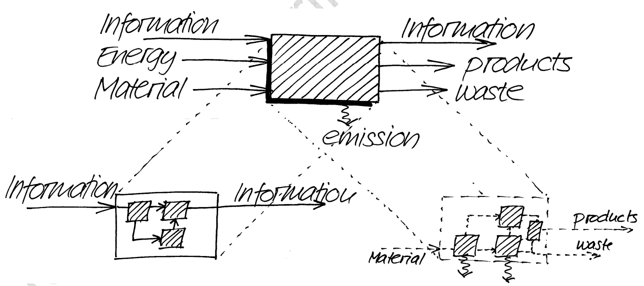


Fig. 7: Black-box modelling-approach, combined with a system hierarchy under different aspects (according to /Züst 1997/)

The simple-minded overtaking of seemingly obvious systems boundaries is risky. These often do not include relevant functional performance areas. Since it is not possible to recognise the effects of potential interference on the system at the beginning of systems design, systems boundaries should be wide enough. During the planning phase, the boundary must be critically examined. At the latest, the precise boundary must be determined before the planning phase is concluded.

Result: The individual results of situation analysis are:

- system boundaries (of the system to intervene and the external systems)
- a structure of the system under investigation
- the determination of the characteristics of the influencing systems and the remaining environment
- an interpretation / evaluation of the situation, for example a strengths-weaknesses and opportunities-threats catalogue (**Fig. 8**, **Fig. 9**)
- a list of the general conditions and further important facts, as well as
- a compilation of the existing solution approaches
- a summary of the problem definition and agreement

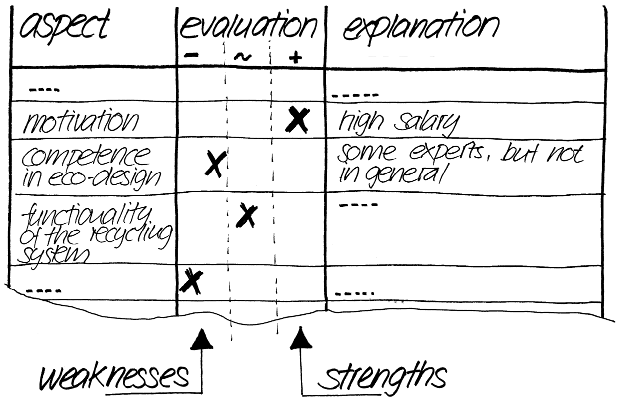


Fig. 8: Example of an analysis of strengths and weaknesses, based on the present state and behaviour of the system in the context of an environmental management system design /Züst 1997/

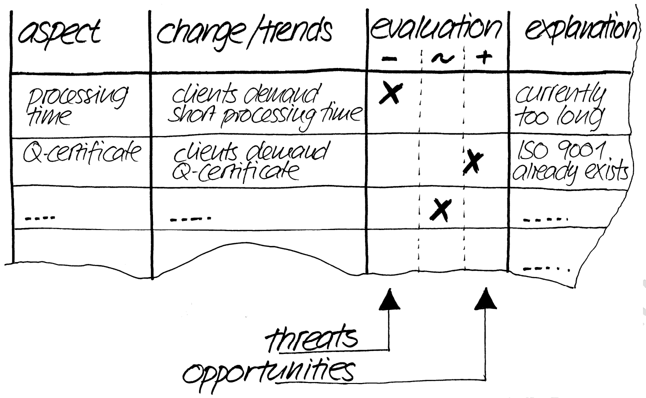


Fig. 9: Example of a opportunities-threat analysis, based on the future analysis in the context of supply chain management /Züst 1997/

Specifics: Situation analysis also requires elucidating and contemplating the future. The prognoses about internal system behaviour, as well as the environment, are not trivial, especially with socio-technical systems. Generally, neither extrapolations nor growth models suffice on their own. The behaviour of the actual system, as well as its interaction and links with its environment, must be fundamentally analysed and assessed. Long-term prognoses are characterised by uncertainty.

Situation analysis should close with the revision and reformulation of the initial problem definition. It should include a short and understandable outline of the most important situation analysis results, as for example

- adequate representation of the defined boundaries of the intervening system, based on knowledge gained from situation analyses,
- precise description of the problem to be solved, based on strengths-weaknesses and opportunities-threats analysis,
- description of the conceived performance expected from new solutions,
- determination of the general framework and the special conditions, as well as
- amount of tolerance in the following search for a solutions.

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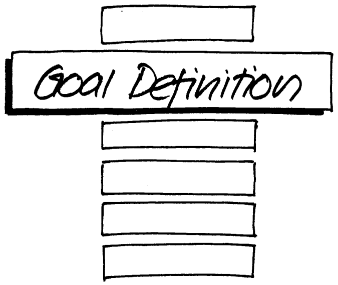
Personal notes:

5.3 Goal Definition



Goal definition uses the results of the situation analysis to identify requirements. The search for problem solutions obtains a clear direction only when goals are set and recognised by the planning team. Goals and external conditions guide concept synthesis and are used as criteria for the later evaluation of alternative solutions.

Purpose: The purpose of goal definition is:

- preliminary, obscure goal projections, which result from situation analysis, are completed, exacted, corrected, systematically structured, and documented as a catalogue of goals from the client's point of view,
- that all constraints (external conditions) which effect the specific space-time context, are determined,
- the requirements (goals and constraints) are guidelines for the successive search for solutions and are available to the planning team, and
- that an information basis exists, based on a written agreement with the client, for the systematic evaluation of possible alternatives, in binding form.

Contents: The catalogue of goals and constraints describes the requirements needed for the solution to be worked out. These requirements set the direction for the solution search. On the one hand, positive expectations, which should be incorporated into the system design, as well as avoidable negative conditions or behaviour, are recorded in the catalogue of goals.

On the other hand, constraints (external conditions), for example, from technical or ethical and societal standpoints, are documented.

Within the framework of problem-solving, various types of goals can be distinguished:

Project goals:	Project goals are formulated at the beginning of a project and are components of the project initialisation. They can include references to the system to be designed, as well as to the problem-solving process.
System goals:	System goals describe demands on the system to be designed or to be changed, and are developed on the basis of situation analyses and the clients preferences. System goals and constraints (external conditions) define the demands on the system.
Process goals:	Process goals refer to the course of a project. They flow primarily into the project management.

During goal definition, system and process goals, as well as the constraints are defined.

Process: The process of defining a goal catalogue can be divided into various planning steps, which occur cyclically:

- first draft of a structured goal catalogue
  - intuitive gathering of ideas for the goal
  - systematic structuring of the goals
- systematic analysis and setting-up of a revised goal catalogue
  - control of solution neutrality and functionality / measurability
  - checking the balance and completeness
  - checking for contradictions and redundancies
- approval of the goal catalogue by the client

Constraints have to be outlined as the ruling context for systems design.

- ***Result***: The result of goal definition, in addition to the outlining of the constraints, is a concisely formulated, structured goal catalogue (see **Fig. 10**).

classes of goals	goal characteristics	extent
functional goals	• processing time • quality •	$\leq$ 5 weeks $\leq$ IT 7 ......
economic goals	• investment • profitability	$\leq$ 1 Mio US$ ......
social goals	• without possibility of dismissal •	Yes .....
ecological goals	• VOC emission •	No

Fig. 10: Schematic representation of a structured goal catalogue, divided into classes of goals, goal characteristics and extent /Züst 1997/

Specifics: The desirable states and behaviour of a system, as described in the goals, are never predetermined, but are based on the clients and the decision makers' expectations. Goals are always subjective. Through rational and systematic goal ranking, conflicts between the involved people can be appeased and overly one-sided procedures can be avoided.

Requirements include

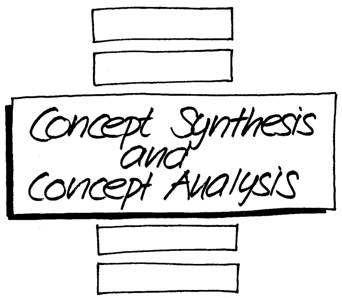
- the target object (e.g. a production system),
- the criterion (e.g. the processing time),
- the actual result (e. g. a maximum of 4 weeks) and
- the time limit (e. g. production system completed by the next 9 months).

There are further formal demands on individual goals, the goal catalogue and on the relationships between goals:

individual goals:	solution independent and measurable
goal catalogue:	comprehensive and balanced
relationships between goals:	non-contradictory and non-redundant

Personal notes

5.4 Concept Synthesis and Concept Analysis



Concept synthesis and concept analysis build on the results of situation analysis and goal definition. Their purpose is to develop alternative solutions and to test them for suitability and feasibility.

Purpose: The purpose of *concept synthesis* is:

- to find ideas for alternative solutions
- to foster the intuitive as well as the systematic synthesis of solution ideas

The purpose of *concept analysis* is:

- to detect unusable or deficient solutions
- to allow screening and improvement of solution ideas
- to reduce the spectrum of alternatives during analysis in order to rise the efficiency of their subsequent assessment

Contents: Concept synthesis denotes the working out of alternative solutions in varying degrees of specification and detail. „Thinking in alternatives " and „from a general to a detailed view" (compare with "basic beliefs and principles") play a major role in this context (see **Fig. 11**).

Concept analysis describes a planning activity, by which insupportable / unusable alternatives are detected and either eliminated or transferred to further improvement. Concept analysis evaluates the extent to which the systems requirements are fulfilled.

Result: The result of concept synthesis and subsequent analysis is a number of feasible alternative solutions for the problem at hand, which have to be evaluated subsequently.

Process: See **Fig. 11**

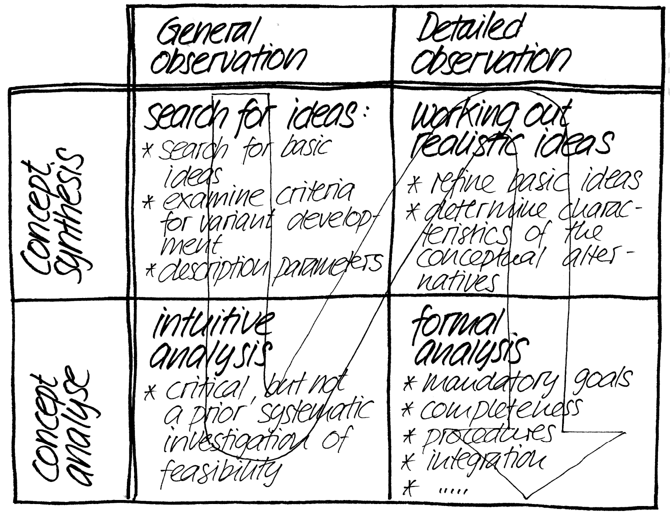


Fig. 11: Detailed working steps of concept synthesis and analysis (/Züst 1997/ according to /Nagel et al. 1982/)

Specifics: In concept synthesis, the creative process must be encouraged. This can be accomplished by removing barriers to creativity and by using methods which foster intuition and systematically promote creativity (e.g. **Fig. 12**).

A rough analysis may be undertaken on the basis of the constraints denoted in the requirements catalogue. Alternatives which have passed through this „coarse filter" are subjected afterwards to a detailed formal analysis. Viability plays a major role in the assessment of the developed solution-concepts.

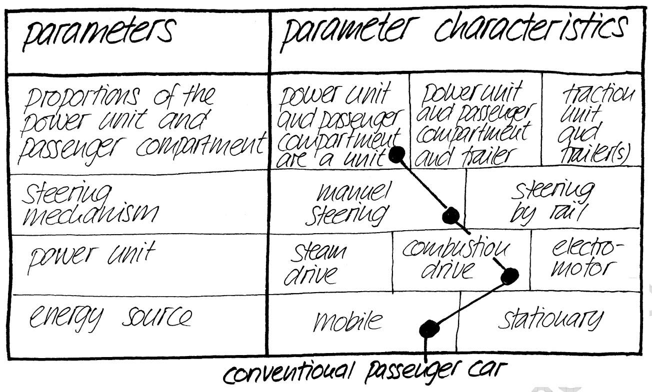


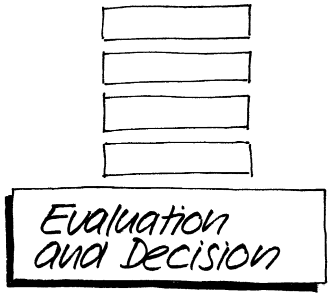
Fig. 12: Example of a morphological matrix /Züst 1997/

Examples of the aspects of a formal analysis are:

- functionality: in normal and unusual cases, and in case of potential accidents
- performance and effects:
  - direct system performance
  - fulfil constraints (external requirements)
  - financial, personnel, organisational and ecological consequences
- integration into the environment
- user-friendliness and maintainability
- ease of implementation
- prerequisites
- comparability of the alternatives
  - solution for the same problem
  - completeness of the solutions
  - degree of concept detail

Personal notes:

5.5 Evaluation and Decision



The last step in problem-solving includes the partial steps evaluation and decision. The feasible solution alternatives at hand have to be evaluated comprehensively, based on non-mandatory requirements from goal definition and possibly on enhanced criteria from concept synthesis and analysis.

Purpose: The purpose of the selection is:

- the clear presentation of the evaluation and decision situation
- the systematic and comprehensive evaluation of the alternative solutions
- to support the decision-makers decision-making and
- a verifiable and transparent selection.

Contents: The evaluation is the basis for the decision. An evaluation is never "objective" in a strong sense, because all evaluations contain subjective assessments of facts and values.

The resulting decision by the authorities and decision-makers should be a free act of will. Therefore, their value system must be considered in the preparations for the decision.

During the preparation for the decision, one strives to:

- transparently model / describe the decision situation
- present all relevant documents in an understandable form to the decision-makers

As an example, the decision-making process can be divided into the following sub-steps:

- listing the alternative solutions

- evaluating and interpretation of the alternative solutions
- making a decision
- substantiation / justification of the decision
- documentation

General Process Framework for Decision-Making:

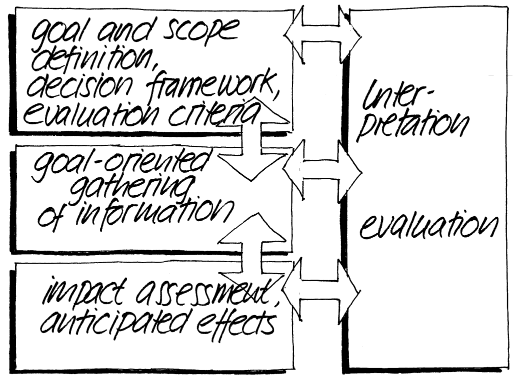


Fig. 13: The four partial steps of decision-making (according to /ISO 14040/)

The first two partial steps: „determination of the decision-making framework and criteria," and „accurate and goal-oriented information-gathering," guarantee that the necessary information and documentation is available for decision-making. The partial step: „evaluating alternatives" denotes evaluation in a narrow sense. Parallel to this, a systematic interpretation and assessment of the individual results have to be undertaken.

The process depicted in **Fig. 13** is a general schema, which must be adapted to the decision-making situation, or if need be, expanded. In practice, the individual work steps occur cyclically.

Result: The result of the evaluation is a recommendation for a decision, which if necessary includes suggestions for further actions and procedures.

Specifics: A significant element of a methodically supported evaluation is the criteria plan. The „criteria“ are the operational measures for systematically determining the extent to which open goals are fulfilled.

It is not always possible to find adequate quantitative criteria. In this case other representative indicators must be defined.

For this reason, the same formal requirements are placed on the individual criteria, as on the goal catalogue as a whole. The measurable variables should be operational. The criteria plan must be comprehensive and balanced. There should be no contradictions between hard criteria and softer indicators, and if possible, there should be no redundancies.

Also to be considered when developing the criteria plan is that the criteria should be as independent as possible, and that they do not influence each other, at least not significantly.

The effort for evaluating suitable assessment methods and the choice of the assessment process should not be underestimated. Especially with mutually dependent assessment criteria, or individual assessment criteria with inconsistent meanings, linear evaluation methods, e.g. grading, weighting and summing up, cannot be applied, or only to a limited extent.

Variants / Criteria	car	puplic transportation	bicycle
driving time	short driving time	average	relatively long
ecological effects	great	low	harmless
pysical & psychological strain	little & great	neither & nor	great & great
transportation costs	very high	moderate	inexpensive
....	...	..	....

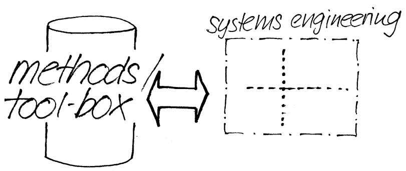
Fig. 14: Example of an assessment in the context of a traffic evaluation based on nominal valuation (according to /Züst 1997/)

In interdisciplinary projects with multi-faceted goals, or when lacking information about the system-effectiveness or when facing de-

pendent criteria which do not allow for a “value synthesis” in a narrow sense, it is unavoidable to use nominal valuations. Additionally, the individual advantages and disadvantages of the alternative solutions may be discussed with the decision-maker. Nominal valuations are thus very important in the assessment (see **Fig. 14**).

Personal notes:

6 Arsenal of Methods in the field of Engineering & Management



A method describes, respectively recommends, a certain procedure, e.g. a way of reaching a certain goal. Systems Engineering is a methodology which regulates the use of various methods in a relatively large problem area.

Evaluation:

There are basically two possibilities for exploring, finding, and evaluating adequate methods:

- Most specific methods are broadly described in literature. They can be found through literature research
- Each specialised field and discipline has its own specific methods. For a specific query in the problem-solving process, conferring with experts may be helpful.

The conscious selection and handling of methods in a problem-solving process is very important. The question of which methods should be preferred for a specific planning step repeatedly arises. This question is especially difficult to answer when little is known about the system, as is the case with a preliminary study.

In practice, it can often be observed, that method implementation is not carried out correctly. Therefore, the following should be observed when applying methods,

- that certain methods can only be applied under specific conditions context
- that methods must be handled correctly, and
- that results achieved through applying certain methods are not necessarily representative for other problems.

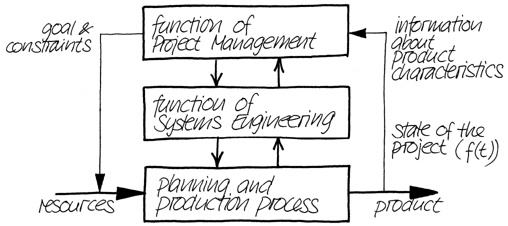
Checklist for the Evaluation of specific Methods

- Is the method adequate, powerful enough and capable of solving the present problem?
- Which prerequisites must be met for a method application?
- How reliable is the method? Which factors limit the application? Are they pertinent? How do they influence the results?
- How much effort does the application need? Is the method efficient?
- Are the data and information necessary for the application available?

(According to /Schregenberger/ and /Züst 1997/)

Personal notes:

7 Systems Engineering and Project Management



Project management has to ensure a successful project course, while Systems Engineering has to ensure the development of an optimal product. Project management co-ordinates and controls the whole project

Definition: A *project* is a unique and time-limited operation or undertaking

A project is usually extensive and complex. Therefore it must be broken down into subtasks. Since several disciplines are usually involved in a project, concurring opinions tend to exist about the available and disposable personnel, finances, materials and time.

Purpose: Project management has to ensure an optimal project course. Project management includes all activities to control the project. This does not include activities which involve the contents of the problem to be solved, but the guidance of the problem-solving process.

Contents: Project management has the following dimensions:

- Functional dimension
  - initiating projects
  - handling projects
  - closing projects
- Institutional dimension
  - developing project organisation
  - integrating and interconnecting the project organisation into the existing organisation of the client
- Personnel dimension

  - defining tasks and roles of the project members
  - involving the people affected by the project
- Instrumental dimension
  - evaluating and incorporating adequate methods for an optimal project course
  - providing adequate tools for an optimal project course

The roles and responsibilities of project management must be clearly defined.

Checklist for Project Management

Setting up project management with a clear vision of the undertaking is especially beneficial. For this purpose, a few questions are listed in the following, which must be answered before starting the project:

- What is the project called? Why is this project being implemented? What are the reasons and incentives? What are the obvious important aspects of the problem?
- What is the goal of the project, i.e. what should be achieved? What benefits are to be expected? Have similar projects already been undertaken?
- Who is going to be involved in the project? Who are the people involved? Who are the people being affected? Where does the project overlap with other undertakings? How are the project's boundaries defined? Who is the project leader? Who is in the project team? Which contact persons are available outside of the project team? How is the project committee or the decision-making board put together?
- What must be taken into consideration? What are the constraints (external conditions?) What are the degrees of freedom? What influences are the most important?
- How should the set goals be achieved? What is the solution strategy? What approach will be used? Are certain milestones already known?
- When should information about the current planning results be passed on? If necessary, how will public relations work be handled? Can something be said already about the intermediate and final decisions to be made? What are they like?
- Which planning results should be documented? How must the documentation be planned, in order to comply with clients needs?
- Which planning process should be evaluated? Which methods could be valuable at which point in time? Which sources of information are available? Which sources of information must be acquired?
- How much does the project cost? How does the project budget look? How can the project be financed?

/Züst 1997/

Execution: During project planning, the following sequence of steps can be effective (/Nagel et al. 1982/):

- Define intermediate goals for individual development and realisation phases
- Define project structure by differentiating partial tasks
- Define the co-ordination and execution of individual partial tasks
- Qualitative and quantitative estimates of personnel, financial, material and time requirements
- Organisational planning: build work groups for partial tasks, plan utilisation of resources, appoint committees for project guidance, determine work regulations,...
- Estimate expenditures (through the project group) and have client approve budget (with reserves)
- Plan intermediate and final deadlines (milestones)
- Determine project information and documentation system

Within the scope of project control, the following measures are necessary:

- Assign tasks, including responsibility and roles
- Direct, motivate and protect employees
- Supervise the problem-solving process, and if necessary, adjust scope, goals and schedule
- Co-ordinate between the client and the project group, as well as between work groups over all life cycles
- Check the deadlines, the efforts, as well as the effectiveness of project organisation and planning of operations

As far as project information and documentation systems are concerned, the following tasks are important:

- determine information strategy including its operations
- project reproting (e.g. about the situation analysis, about the evaluation,...)
- document the knowledge acquired
- report decisions

14 Critical Success Factors of Project Management

Results of an empirical investigation (Keplinger 1991)

1. (Top) Management support of the project and the respective goals facilitates success, e.g. eases resource allocation.
2. Good external relationships with implementers, customers and users.
3. Clearly defined project goals, and in the case of changes, again clearly defined agreements.
4. Concentration on the starting phase, i.e. the development of a common problem understanding, creation of a functional team and joint planning of the execution activities.
5. Sufficient project planning (organisation, process schedule), joint, brief and intensive, not too detailed in the beginning and recognise phase goals / milestones.
6. Appropriate project control, i.e. regular compilation of status and progress while focusing on key factors.
7. Open, direct communication and information, i.e. inform yourself and do not wait to be asked, internal and external written brief reports, as well as verbal communication.
8. Situation-appropriate methods and tools: simple aids are helpful, network schedules and IT-supported project management systems are not the (only) factors of success.
9. Purposeful, not bureaucratic, organizational structure, i.e. keep teams small, include a wider circle of people by conveying information, transparent tasks and responsibility sharing within the project team, as well as between the team and the decision-making committee. The core team should work as intensively as possible on the project.
10. Sufficient management competence of the project leader. Successful project leaders only make use of their authority in exceptional cases. They lead through powers of persuasion.
11. Ability, authority, experience of the project leader, i.e. leadership qualities are more important than discipline-specific and administrative abilities. The project leader is the success factor.
12. Situation-appropriate leadership style of the project leader, i.e. cooperative in normal cases, authoritative in exceptional situations, primarily task oriented, able to solve conflicts quickly, chronic conflict partners may be removed from the team (in a fair way).
13. Constellation of a competent project group, i.e. preferably qualified and team oriented employees, a stabile team, sufficient time for project work, avoid substitutes as much as possible.
14. Motivated project teams.

/Keplinger 1991/

Personal notes:

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